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DIGITAL ENHANCEMENT OF COMPUTERIZED AXIAL TOMOGRAMS

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Abstract

A systematic evaluation has been conducted of certain digital image enhancement techniques performed in image space. Three types of images have been used, computer generated phantoms, tomograms of a synthetic phantom, and axial tomograms of human anatomy containing images of lesions, artificially introduced into the tomograms.

Several types of smoothing, sharpening, and histogram modification have been explored. It has been concluded that the most useful enhancement techniques are a selective smoothing of singular picture elements, combined with contrast manipulation. The most useful tool in applying these techniques is the gray-scale histogram.

Summary

NASA developed technology has been applied to the enhancement of computerized axial tomograms of human anatomy. The work was performed on an image analysis system developed for the inspection of aerospace structures. The tomograms were supplied by the Cleveland Clinic Foundation in the form of computer readable magnetic tapes.

A systematic evaluation was conducted of a repertory of digital enhancement techniques performed in image space. Three types of images were used: computer generated phantoms, tomograms of a synthetic phantom, and tomograms of human anatomy containing images of lesions, artificially introduced into the tomograms.

The repertory of enhancement functions included several types each of smoothing, sharpening and histogram manipulation. The functions were applied in an orderly manner to several of each of the three types of images. The input parameters were varied systematically.

The following conclusions were reached for the type of images investigated in this program:

1. Selective smoothing of singular picture elements is most useful for reducing noise spikes.
2. Contrast manipulation is the most effective enhancement method.
3. The gray-scale histogram is the most useful tool in applying these techniques.

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Introduction

The raw images produced by computerized axial tomography possess certain shortcomings. Fine structure is frequently obscured by limited resolution and noise introduced by both the X-ray sensors and the reconstruction algorithm. These shortcomings are shared with those of radiographic images produced in the nondestructive inspection of materials and structures. The resolution of such problems in aerospace applications is currently under investigation at NASA, Lewis Research Center. A real-time computerized radiographic inspection facility has been developed¹.

To explore common problems, a cooperative program between the Nondestructive Evaluation Section of Lewis Research Center and the Division of Radiology of the Cleveland Clinic Foundation has been initiated. It is coordinated by the Technology Utilization Office of Lewis Research Center. The work is being conducted by NASA personnel in the laboratories of the Nondestructive Evaluation Section.

Axial tomograms of human anatomy are supplied by Cleveland Clinic. They are transferred in the form of computer readable magnetic tape. They are processed on the NDE section computer, using a repertory of enhancement functions developed for on-line radiographic inspection. Currently, the investigation is limited to operations in image space. It is planned to be extended to Fourier filtering and analysis in Fourier space.

The tomographic images supplied by Cleveland Clinic consist of 256 lines of 256 square picture elements. The image analysis hardware processes images of 490 lines of 512 rectangular picture elements. The elements have an aspect ratio of 4:3, the broadcast television standard. For display purposes, it is necessary to transform the Cleveland Clinic images by cyclically repeating picture elements. However, they are stored in the computer

mass memory, and processed, as 256 X 256 arrays.

The image analysis hardware uses a range of brightness values from 0 (black) to 255 (white). The tapes supplied by Cleveland Clinic use arbitrary X-ray absorption values. They are transformed on reading to "delta numbers" from -1000 to represent the X-ray film density of air (black) through +1000 to represent bone (white).

Procedure

Three classes of enhancement functions were explored: image smoothing, image sharpening, and histogram modification. These techniques are described more fully elsewhere². Four types of image smoothing functions were used:

1. Weighted gray value averaging over a neighborhood, 3 picture elements wide by 3 high. The weight given each element is an input parameter.
2. A weighted median otherwise identical to item 1.
3. A replacement of a neighborhood of picture elements by the mean of the neighborhood. The size may be made 2 X 2, 4 X 4, 8 X 8, or 16 X 16.
4. Selective averaging, the criterion being that the central point in a 3 X 3 neighborhood be out of a specified range. If the element is not out of range, it is not averaged.

Two types of sharpening functions were explored:

1. Laplacian,
2. Root-mean-square gradient.

Two types of histogram modification were investigated:

1. Contrast expansion, in which a specified input range of gray values is transformed to a different specified output range. Picture elements falling outside the input range are transformed to the minimum or maximum value.
2. Gray value segmentation in which an arbitrary number of gray value boundaries is specified, and any given input value is transformed to the mean of the range in which it falls.

These functions were systematically applied to 3 types of images:

1. Computer generated phantoms having irregular boundaries. The boundaries, gray values, and superimposed noise are input parameters. A typical phantom image had an average gray value on one side of the boundary of 100, and 104 on the other side (in terms of the hardware values). Random noise having a range of ± 2 was superimposed on the image, producing a range of 98 to 102 on one side, and 102 to 106 on the other. This image, contrast expanded to full scale, is shown in figure 1.

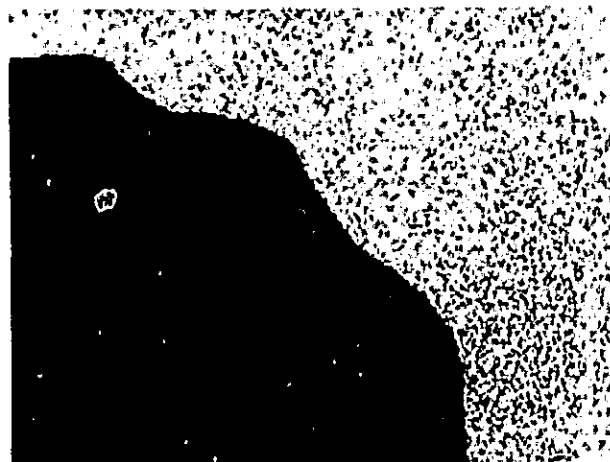


Figure 1. - Computer generated phantom.

2. Several tomograms of a synthetic phantom. This was a nylon body of irregular shape immersed in varying strength solutions of potassium iodide and water. One of these images is shown, contrast expanded to full scale, in figure 2.

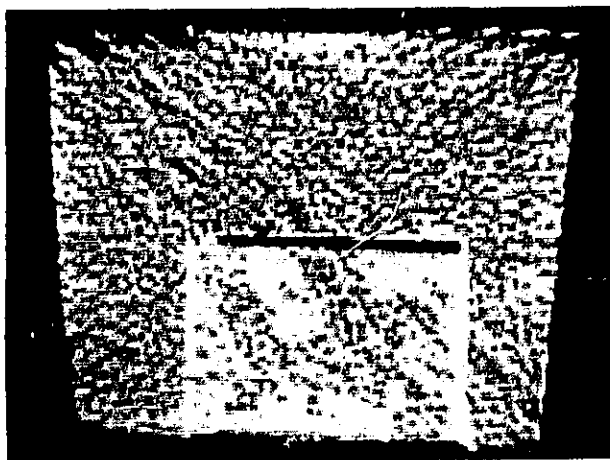


Figure 2. Tomogram of synthetic phantom.

3. Several tomograms of human anatomy, to which images of lesions were artificially introduced. One of these is shown full scale in figure 3, with the locations of the artificial lesions indicated by the labels a, b, c, d, e, f, and g.

In all cases, the anomalies were not immediately apparent to the unaided human eye.

Several sets of input parameters were tested for each function. Each function was, in turn, applied to several of the 3 types of images. Combinations of functions were used when that appeared

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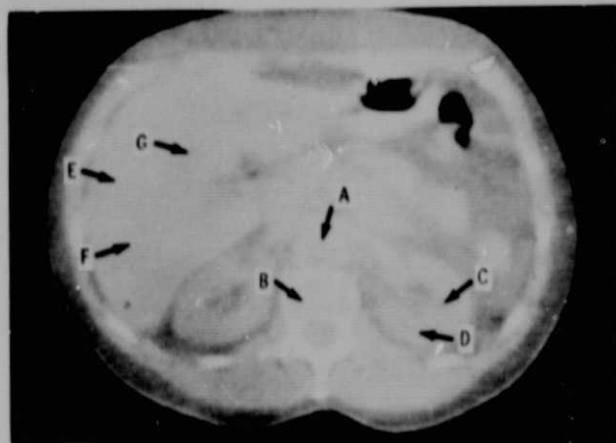
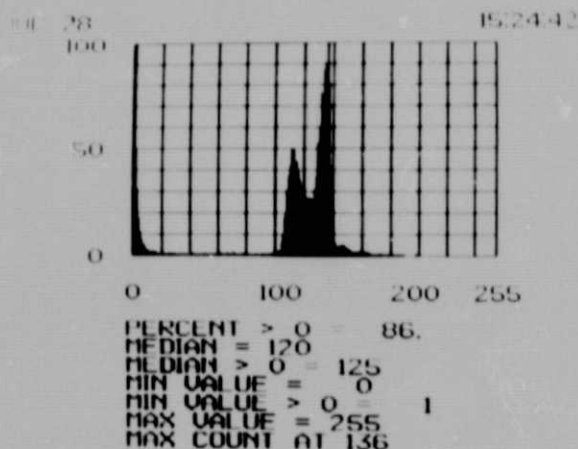


Figure 3. - Tomogram of human anatomy. Pointers indicate location of lesions.

to be a logical procedure. The output images were inspected visually in an attempt to locate the known boundaries or anomalies. When necessary, histograms of the various images were produced.

The gray-value histogram, presented on the video monitor, is a plot of the number of picture elements corresponding to each gray value. It is taken over a rectangular region, defined by a cursor displayed on the monitor. Typically, it covers approximately 40 percent of the total image area. It is shown as a white rectangle in figure 3. The histogram is normalized to a maximum ordinate value of 100. The number of picture elements at 0 (black) may be omitted from the normalization computation in response to a prompt by the computer program. The plot illustrated in figure 4 uses the bright-



'RED' IMAGE, FULL SCALE

Figure 4. - Histogram of figure 3.

ness values produced by the image analysis hardware (0 to 255).

The histograms were used both to define the values of input parameters to the various functions, and to analyze their effect on the output image.

Investigations conducted on the computer generated phantoms revealed that random noise reduces the effectiveness of the two types of image sharpening functions. In the absence of noise, both of these functions clearly reveal the boundary between areas of differing gray value, even when they are virtually indistinguishable by the unaided eye. A thresholding process is especially effective. In this case, a histogram is generated of the gradient image. The histogram is used to define a threshold value. All values greater than this threshold are set to black, and all others set to white. This binary image is then logically summed with the original image, often with dramatic results.

However, the presence of random noise introduces a speckle pattern superimposed over the gradient image. This pattern can be minimized either by smoothing the original image, or by selectively discarding isolated black picture elements on the binary gradient image. But both procedures tend to obscure the boundary. When the range of noise is such that there is an overlap of gray values between the two regions, the methods fail completely. This is the case with the computer generated phantom described herein, and is apparently the case with the tomograms.

The various smoothing procedures reduce the isolated noise spikes in the images. However, the more effective the procedure in reducing noise, the more it obscures boundaries. The only one of these functions which leaves recognizable boundaries is a selective averaging procedure. In this procedure, each picture element is compared with the range of its 3 X 3 neighbors. If it falls outside a defined multiple of that range, it is replaced by the mean of the neighborhood. Otherwise, it is ignored. It can be applied either before or after a contrast expansion, and can be reapplied several times in succession. It produces a very clean looking image, with little apparent ill effect on the boundaries. However, the cleaning process may possibly eliminate texture, which may be useful to the experienced eye in detecting anomalies.

Expansions of limited ranges of gray values are most effective. The histogram of the raw image is useful in defining the ranges to be expanded. Several successive expansions revealed all of the known anomalies in the images under investigation. The histogram of figure 3 is shown in figure 4, and two expansions are shown in figures 5 and 6.

In figure 5, the values between 127 and 137 have been expanded to full scale. Note that this makes the lesions labeled "e" and "f" in figure 3 visible. Similarly, in figure 6, the values between 140 and 150 have been expanded to full scale, making the lesion labeled "b" visible.



Figure 5. - Contrast expansion of figure 3. Pointers indicate locations of lesions.

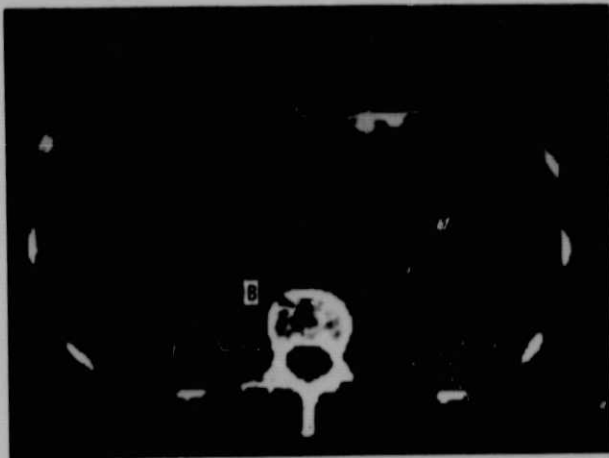


Figure 6. - Contrast expansion of figure 3. Pointer indicates location of lesion.

Conclusions

A systematic investigation of several image enhancement functions with varying input parameters applied to three types of images produced the following conclusions:

1. The application of certain digital image enhancement techniques substantially increases the visibility of anomalies in tomograms of human anatomy.
2. Image sharpening is of little value, apparently because of the low signal to noise ratio and the small variations in the regions of interest.
3. Most of the smoothing techniques "smear out" too much fine structure. Selective averaging of singular picture elements produces a clearer image, but may possibly obscure texture which is useful in identifying anomalies.
4. Contrast expansion is of greatest value. However, its use must be guided by use of the gray-scale histogram.

References

1. E. Roberts, Jr., "Real-Time Radiographic Inspection Facility," NASA TN D-8529, 1977.
2. R. C. Gonzalez and P. Wintz, Digital Image Processing. Reading, Mass.: Addison-Wesely, 1977.

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